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A New Paradigm for Ocean Color Satellite Calibration: highly accurate, low uncertainty, hyperspectral radiometric measurements form autonomous platforms (HyperNAV-II)

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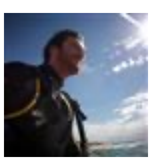


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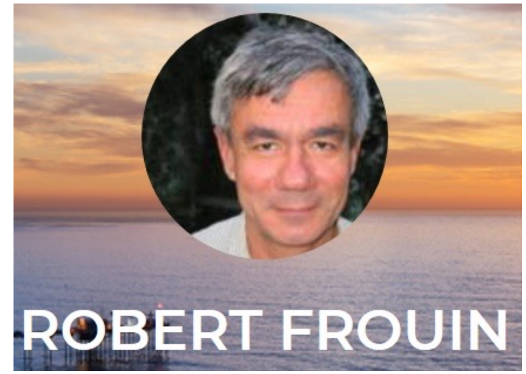


Paul Chamberlain

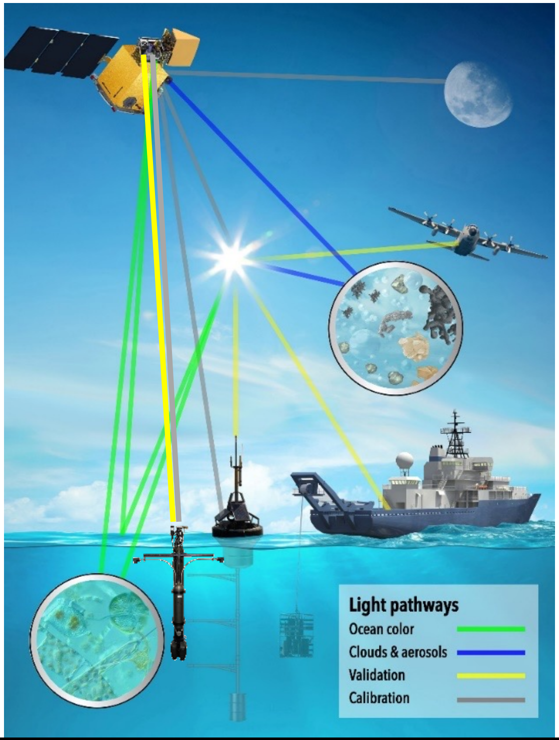
PACE

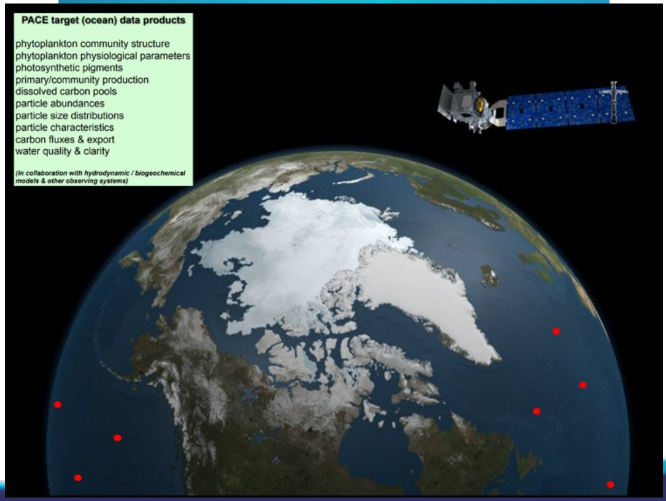
HyperNAV Relevance

NASA's future PACE satellite mission will provide unprecedented data of the world's ocean ecosystems, biogeochemistry, and carbon cycle.

The quality of the PACE data is reliant on collection of high accuracy in situ radiometric data to ensure the satellite ocean color sensor is calibrated and characterized routinely and in near-real time.

Goal: Develop, test and establish a cost effective, reliable, end-to-end sustainable operational SVC program to support the PACE mission using the HyperNAV system.





HyperNav Project Overview

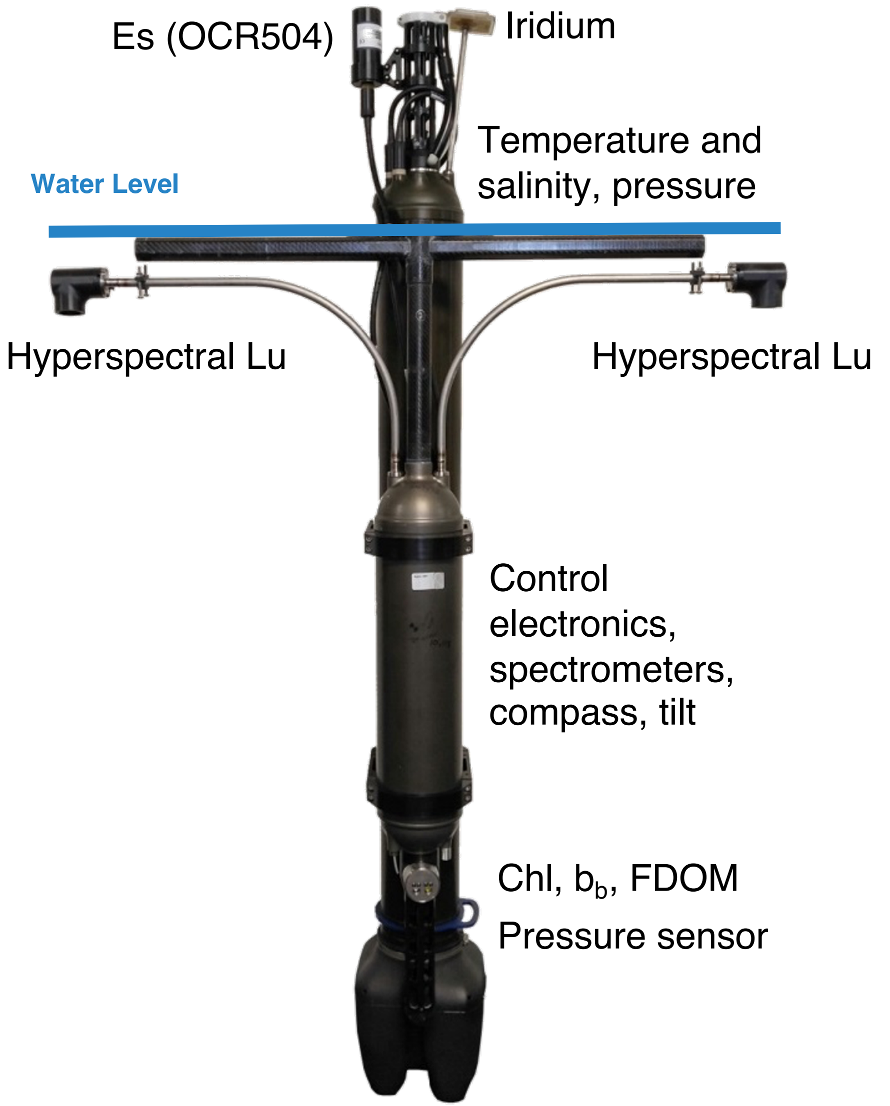
Approach: primary phases.

1. Engineering improvement efforts of the HyperNAV to insure a fully operational SVC system. (YR 1)
2. Conducting several field experiments of HyperNAV systems to validate and verify instrument performance and to identify an optimal SVC location. Refinement of command/control for HyperNAV to a geographical region optimal for *in situ* data collection for SVC, NRT data processing / delivery. (YR1-2)
3. Establish and maintain continuous operational deployments of HyperNAV at selected SVC location to provide high quality radiometric data for the PACE mission. (YR 3-4)

TRL state of HyperNAV progression from 6 to TRL 9

HyperNAV Program Technology

1. **High accuracy** and **spectral resolution dual radiometric sensors** with **low uncertainty**
2. **Integration** with an autonomous float platform (**SBS Navis**) for optimized for collection of **radiometric**, optical, and physical data with **high vertical resolution** near the sea surface
3. A **real-time** data acquisition and processing **software system** to produce the highest quality, lowest uncertainty **data** needed by **NASA** for **satellite calibration**
4. A **mission command/control system** to **optimize data collection** from HyperNAV for satellite calibration and **continuous operations** within a selected **region**



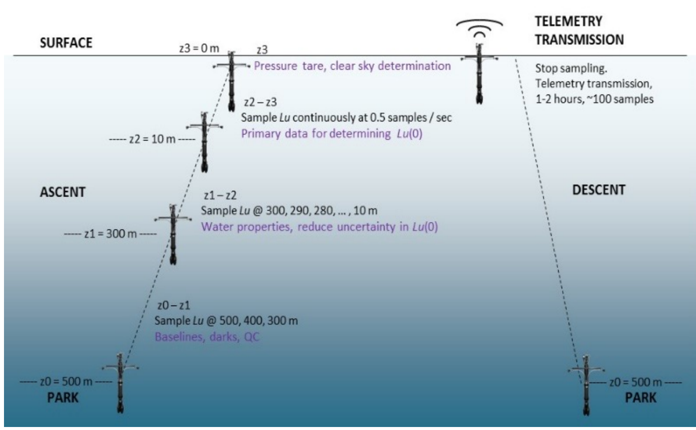
HyperNAV-SVC
with Navis Float

Evolution of HyperNav technology

- **Demonstrated capabilities to resolve the underwater spectral radiance fields**
  - Spectral resolution: < 2 nm across 350 to 900nm range
  - Spectral accuracy: ~0.1 nm
  - Total radiance uncertainty: < 4% in UV-G, 6 % in R-NIR

Source	380nm	412nm	443nm	490nm	510nm	550nm	665nm
Calibration	1.88	1.87	1.80	1.74	1.68	1.68	1.71
Irradiance Standard	0.55	0.51	0.48	0.44	0.42	0.4	0.34
Reflectance Target	1.1	1.1	1	0.9	0.8	0.8	0.9
Geometric Effects	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Reproducibility	0.23	0.23	0.23	0.23	0.23	0.23	0.23
Instrument	1.43	0.71	0.64	0.45	0.66	0.46	1.17
Polarization	0.9	0.5	0.4	0.1	0.06	0.07	0.5
Thermal	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Immersion	0.43	0.45	0.45	0.36	0.4	0.39	0.3
Integration Time Linearity	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Counts Linearity	0	0	0	0	0.01	0.03	1
Stray Light	0.12	0.1	0.09	0.08	0.05	0.04	0.09
Wavelength @ Cal	0.19	0.15	0.13	0.09	0.08	0.06	0.03
Wavelength @ Field	1	0.1	0.1	0.2	0.5	0.2	0.1
Field	2.58	2.55	2.54	2.54	2.62	2.78	5.42
Self-shading	0.3	0.26	0.22	0.24	0.32	0.56	2.7
Tilt Effects	2.2	2.2	2.2	2.2	2.2	2.2	2.2
Biofouling	1	1	1	1	1	1	1
Wave Focusing	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Depth Uncertainty	0.7	0.56	0.54	0.54	0.82	1.14	4
Surface Transmittance	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total Combined, k=1	**3.5**	**3.2**	**3.2**	**3.1**	**3.2**	**3.3**	**5.8**

- **Meets SVC requirements: high resolution, low uncertainty radiometric data.**
  - Full water column profile (surface to >500m)
  - Dual radiance heads, integrated with float platform
  - Reduced errors in extrapolation to Lu(0-)
  - Fully autonomous, easy to deploy
  - Minimization of self shading
  - Integrated shutters (darks)

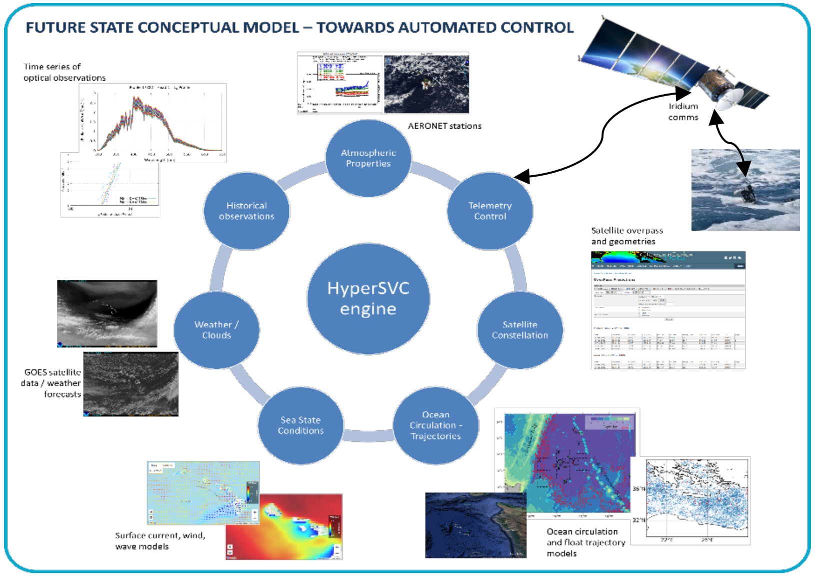


- **Advantages of using profiling floats for SVC purposes**
  - Full water column profiles of upwelled radiance
  - Reduced bio-fouling via parking the float at depth (500m)
  - Easy to deploy/recover – portable
  - Augments other moored cal/val sites
  - Enables rapid collection of vicarious calibration data.

End-to-End operational System

SVC Requirements

- Atmospheric aerosols in the region of the in situ data collection must be or maritime origin (non absorbing, low aerosol optical thickness)
- Sea Surface should be free of whitecaps (low wind speeds)
- Water leaving radiance should be uniform over spatial scales larger than the pixel resolution of the satellite sensor
- Cloud free conditions
- Low in-water bio-optical property complexity and concentrations.
- Low spatial variability in the in water optical properties.
- *In situ* data acquisition must coincide with the satellite overpass (+/- 1 hour)



Key Challenge for using floats for SVC

- Floats can only transmit and receive data when the float has surfaced
- Atmospheric and Ocean conditions can vary (time and space)
- Floats drift slowly at depth – not static location

So when should the float undertake a profile and obtain data that meets the requirements for SVC purposes?

Development of prediction system that optimizes in situ data collection for SVC that can automatically command (operate) the HyperNAV float.

- Next mission configuration to the HyperNAV float
- Profiling schedule
- Park depths
- Estimated trajectory / location
- Surface Acquisition durations

HyperNav Data processing Level scheme

Level 0
- Data received.
- Unpacked.
- Communication artefacts removed.

Level 1 A&B
- A: Apply radiometric calibration
- B: Append ancillary data (CTD profile, location)
  - Compute exact depth of each Lu sensor
  - Apply immersion coefficient
  - Flag data (Tilt, Shade, Clouds)

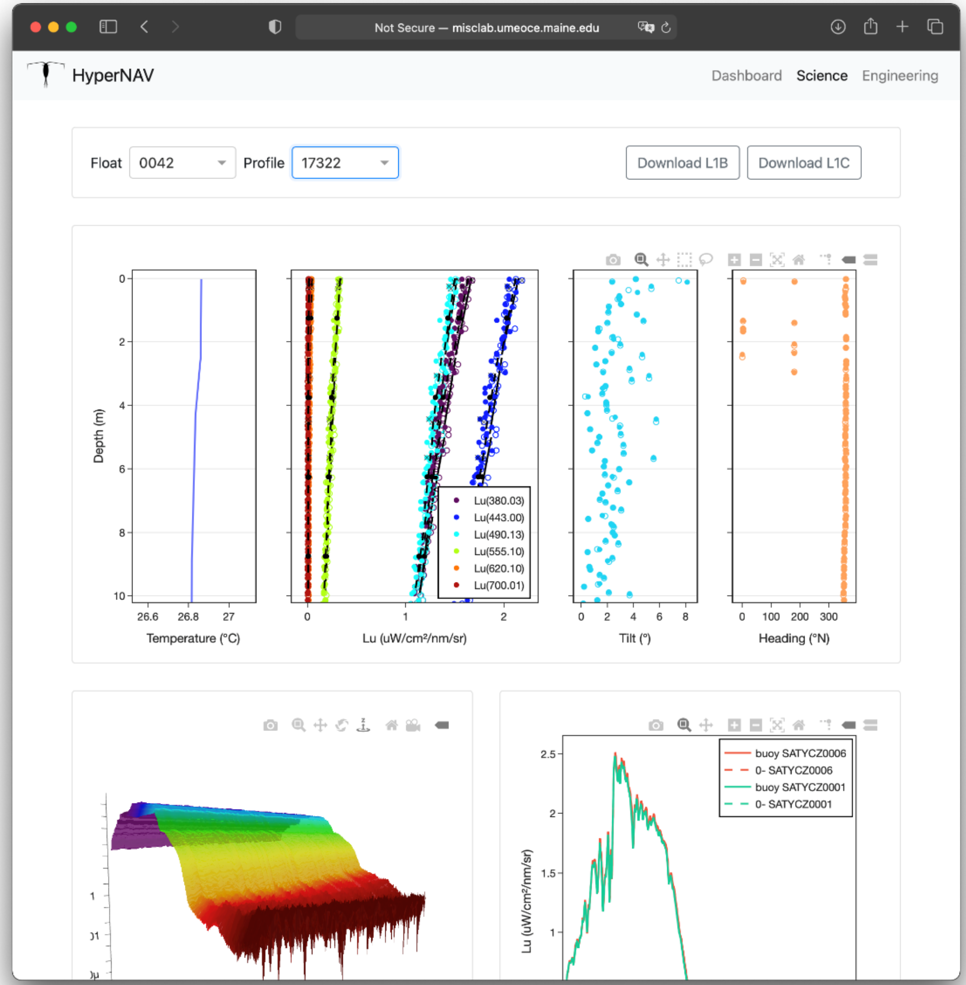
Level 1C
- Extrapolate to z=0-
- Compute KL
- Quality check KL
- Estimate variability
- Compute uncertainty for each head
- Flag data (inconsistent KL)

Level 2
- Merge Lu from both heads
- Compute Lw
- Remove BRDF to get nLw
- Clear sky modeled hyperspectral Es from Es at (4 wavelengths)

Level 3
- Compute Rrs
- Apply satellite spectral weighting for matchup

Real Time Data Visualization

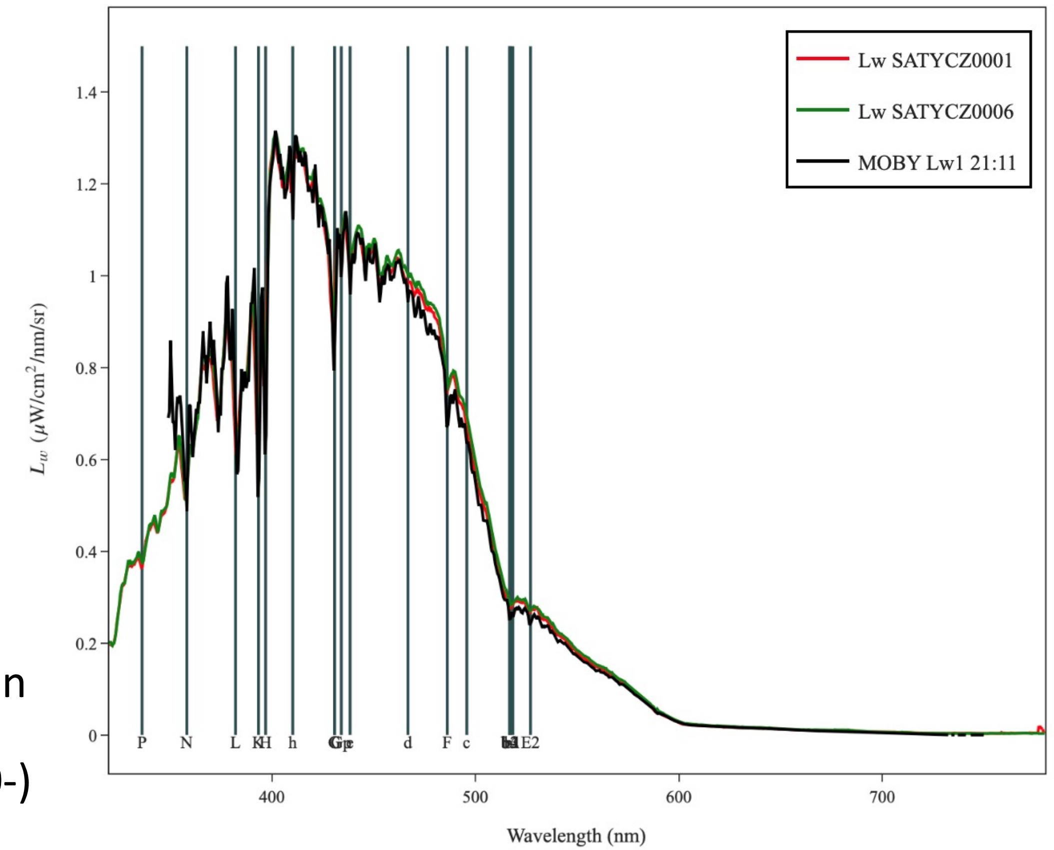
- Near real-time report of HyperNAV's observations
- Optical processing is performed as soon as data is received
- Interactive plots and data are available within ~3 min:
    - Monitor performances of HyperNAVs deployed
    - Validation of processing methods applied
    - Near real-time products available to the PACE team



Output Parameters

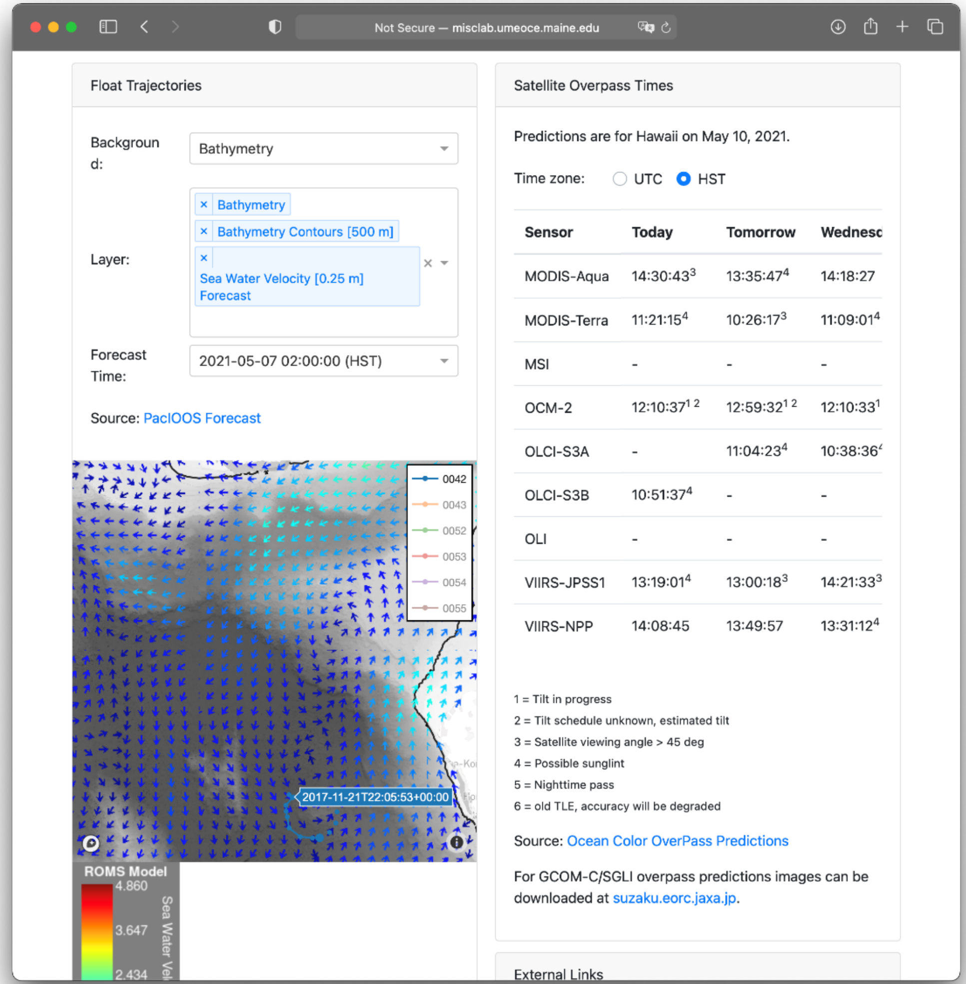
- Parameters available:
  - Lu: profile, 10 cm, 0-
  - K_L
  - Lw
  - nLw (corrected for BRDF)
  - Modeled Es
  - Rrs
  - Product quality (good, questionable, bad)

- HyperNAV and MOBY radiance spectra (Lw) retrieved during previous deployment in Hawaii on Nov 18, 2017. The distance between the two sensors was 158 km.
- Extrapolated Lu(z=10 cm) to Lu(z=0-) using K_L that was fit to the profile between 3 m and 10 cm.



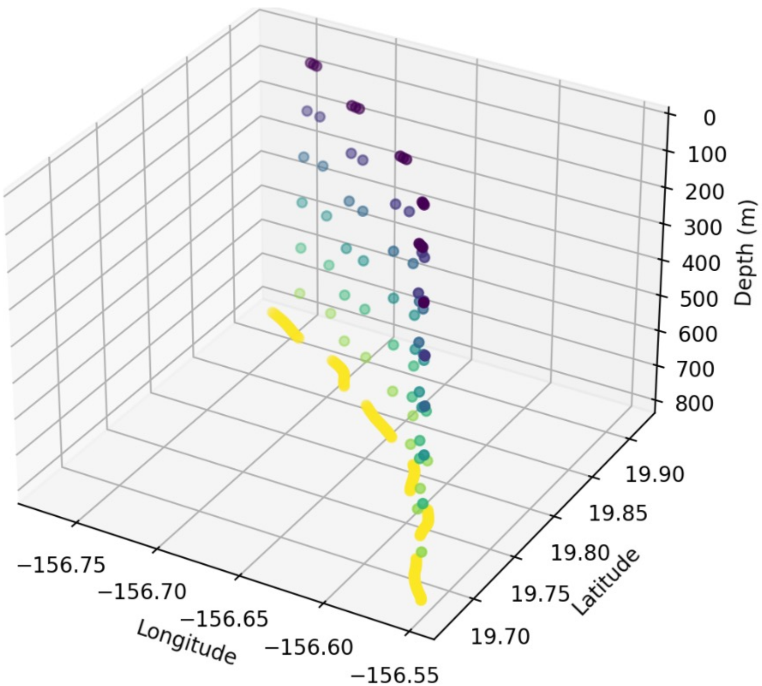
Data Visualization
Main dashboard view

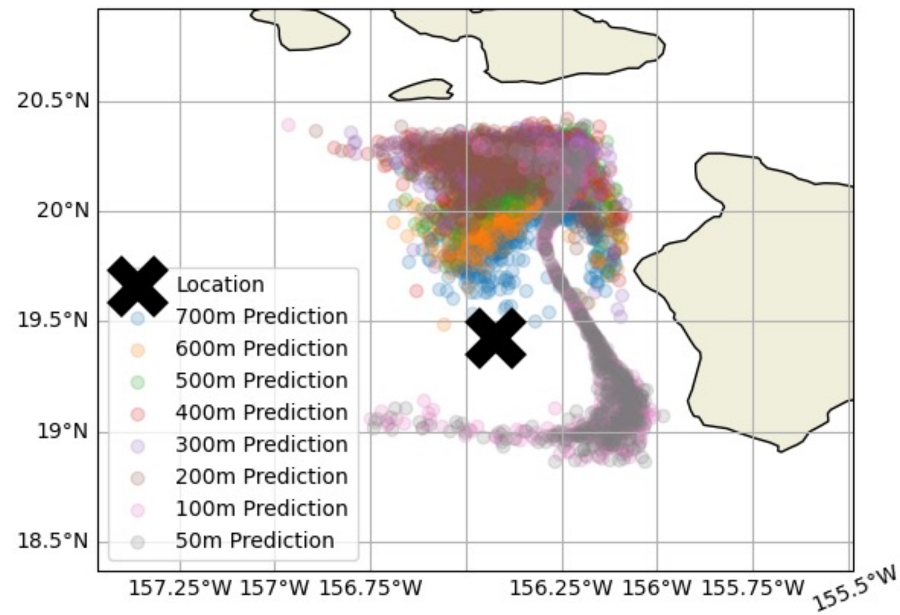
- Support field operations
- Map of HyperNAV trajectories updated in real-time with option to overlay weather forecasts, ocean forecasts, and bathymetry from PacIOOS.
- Integrated prediction of float positions (up to 3 days)
- Display Ocean Color satellites overpass times for the region of interest



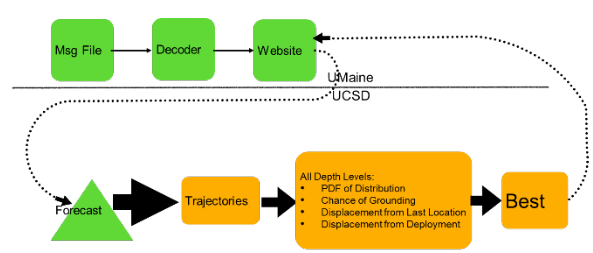
HyperNav location Modelling

High Resolution 3D Prediction Based on Ocean Parcels





3 Day Trajectory Predictions Based on PACIOOS Current Forecast in Near Real Time



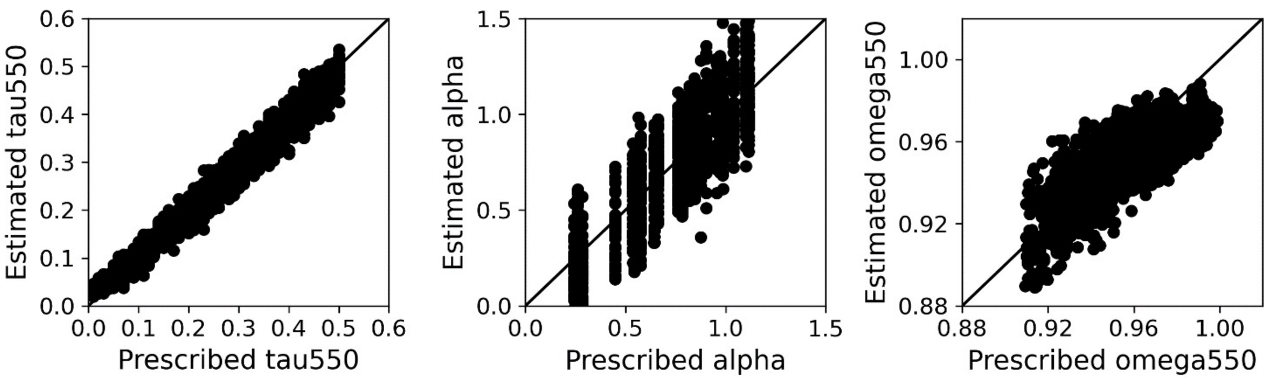
Next Field Campaign Hawaii June 2021

PRIMARY Objectives

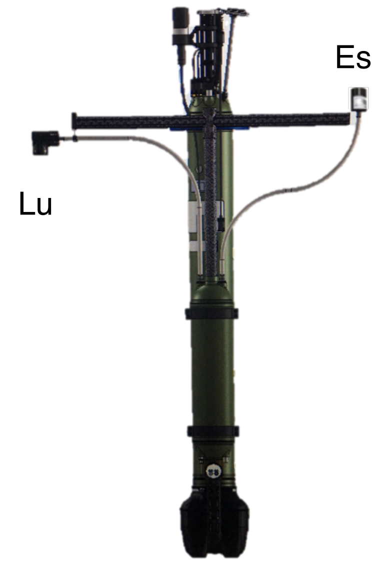
- HyperNav systems performance
- End-to-end processing and data delivery in NRT
- Obtain several *in situ* measurements for matchup comparisons
  - Deployment of 2 HyperNav float systems off Kona, HI
  - Comparisons with MOBY using freefall HyperNav system
  - Clear sky, high altitude measurements with HyperNav at Mauna Loa Observatory
  - Comparison with several Ocean Color Satellites

In development - Aerosol retrieval

Aerosol properties (optical thickness, τ, single scattering albedo, ω) may be inferred from HyperNAV spectral downward irradiance measurements in clear sky conditions and used to check atmospheric correction scheme.



Bayesian inversion yields acceptable accuracy on τ and ω at 550nm and τ spectral dependence α for mixtures of cont., mar., and desert aerosols



Concept: HyperNav system with hyperspectral Lu and Es

Mahalo